VTT Technical Research Centre of Finland

Effects of accelerated carbonation on carbon dioxide uptake and compressive strength of biomass ash artificial aggregates

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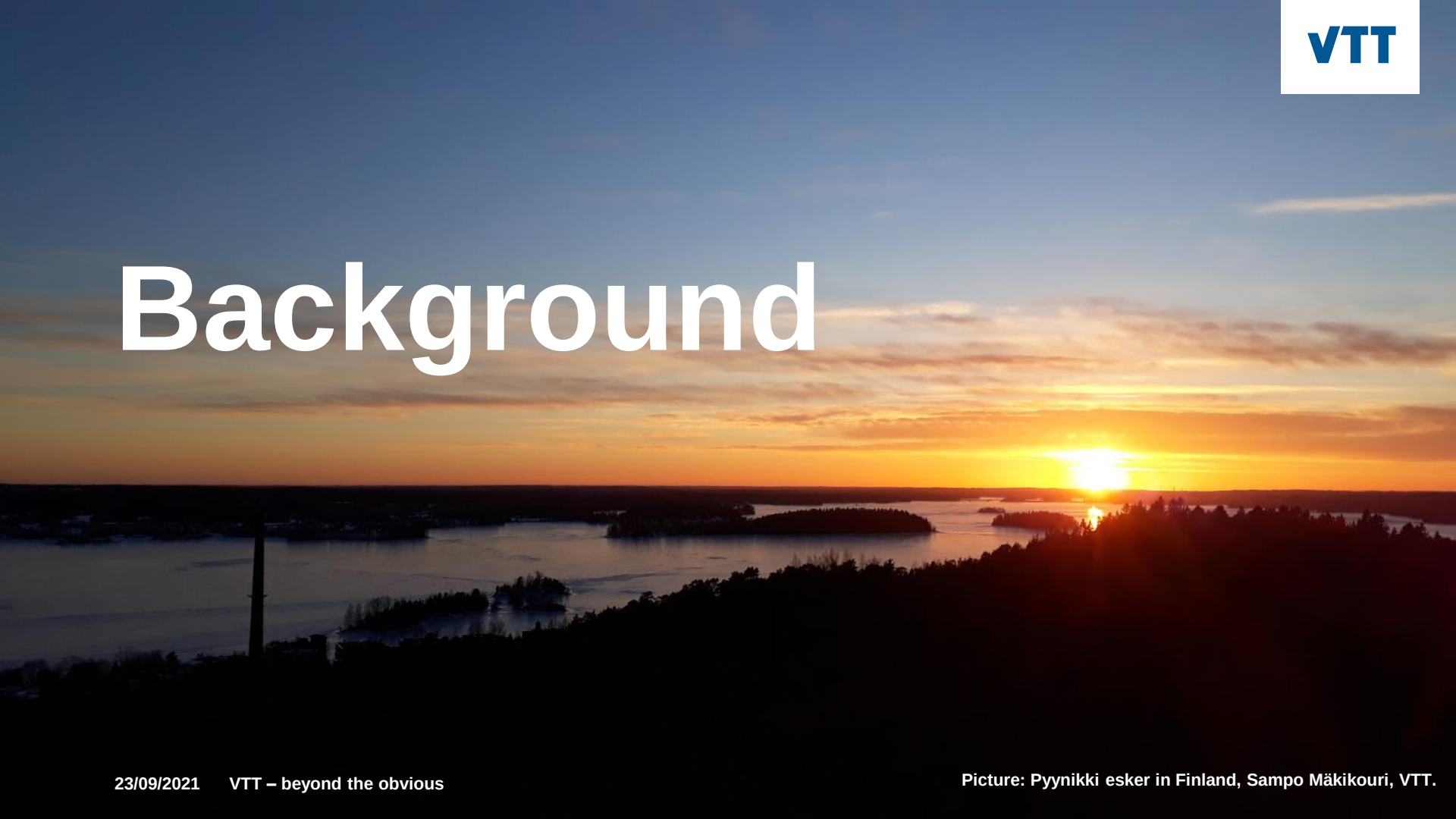
Background



Picture: Pyynikki esker in Finland, Sampo Mäkikouri, VTT.

Climate change strategy in Finland

- Carbon neutral Finland by 2035

Finnish Government, 2019. Government programme.

- Construction industry roadmap: reduce 66…78 % of CO_2 emissions by 2035

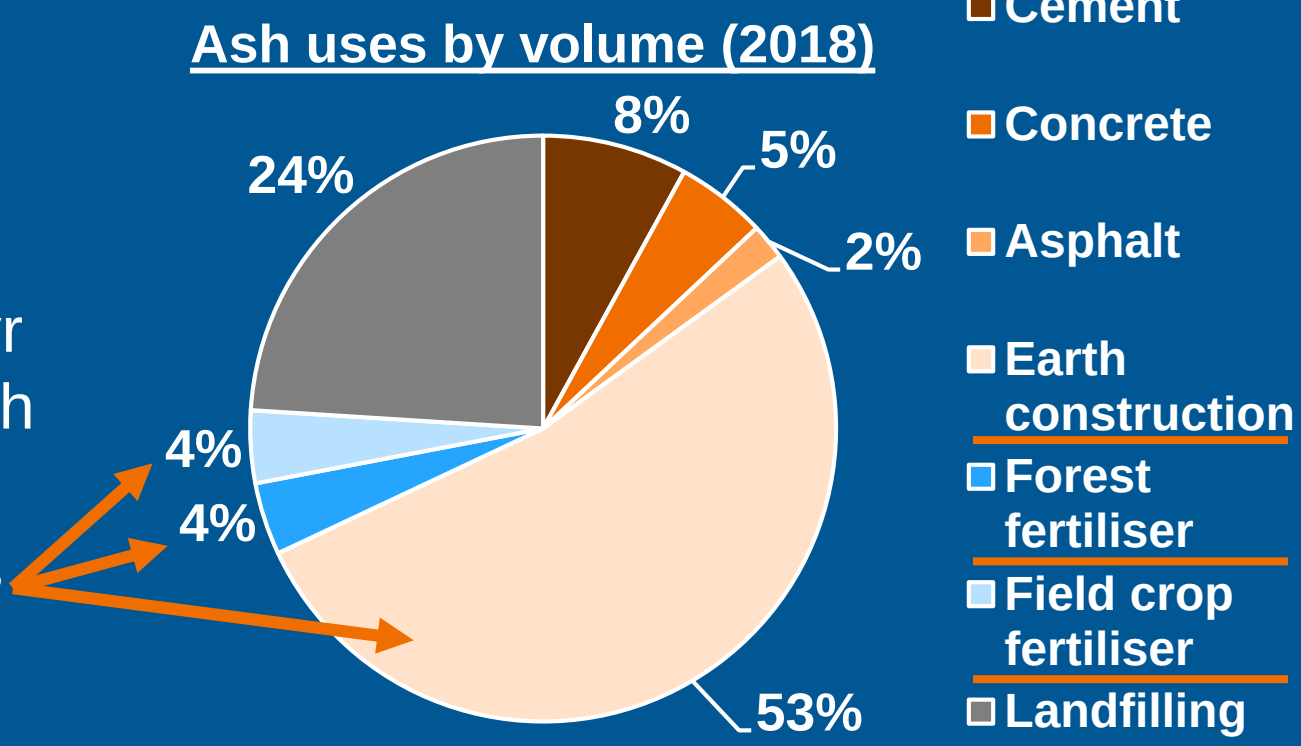
Rakennusteollisuus, 2020. Vähähiilinen rakentaminen 2035.

Image: Pixabay

Ashes in Finland

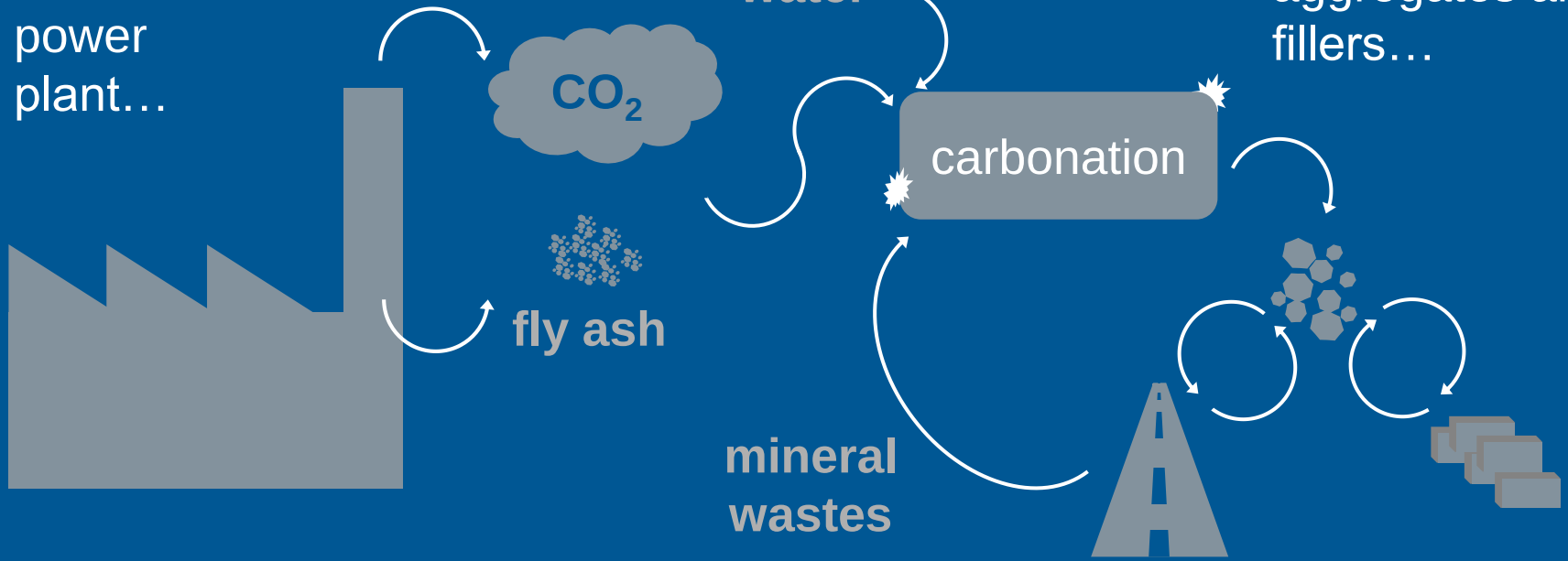
- Estimated current availability:

~ 1 300 000 t/yr in total, of which ~ 500 000 t/yr biomass ashes



Biomass ash aggregates with CO_2

Your local power plant…



…could provide aggregates and fillers…

…for a zero-waste carbon neutral construction industry.

Potential benefits from artificial aggregate production from biomass ashes

- Accelerate carbonation of ashes for a climate benefit
- Substitute more energy intensive production methods (e.g. expanded clay aggregate)
- Reduce the use of virgin raw materials
- Reduce transportation, when ashes are used for construction in the same city

Additional business motivation

- Aggregate prices in Finland
  - 88.3 €/m^3 expanded clay aggregate [1]
  - 27.6 €/m^3 crushed rock fines 0-5 mm [2]
- Ash disposal costs in Finland: landfilling 90…170 €/t [3]
- Avoided CO_2 emissions, when substituting expanded clay aggregates
  - 400 kg CO_2/t aggregate [4]
  - 45 €/t CO_2 in EU ETS [5]

  = 18 €/t aggregate

References:
[1] Taloon.com, for >20 m^3 orders, 4.5.2021, .
[2] Rudus, incl. transportation to VTT Espoo, 100 m^3 order, 4.5.2021, Rudus, .
[3] Based on a few openly available landfilling price lists, 2021.
[4] co2data.fi, expanded clay crushed aggregate, 4.5.2021.
[5] Chestney, N., Reuters. EU carbon price hits record high above 45 euros a tonne, 20.4.2021 .

Ash characterisation

Picture: Sampo Mäkikouri, VTT.

Ash samples

- Biomass fly ash A: wood chips as fuel
- Biomass fly ash B: wood, peat and paper sludge as fuel

Chemical composition of ash samples

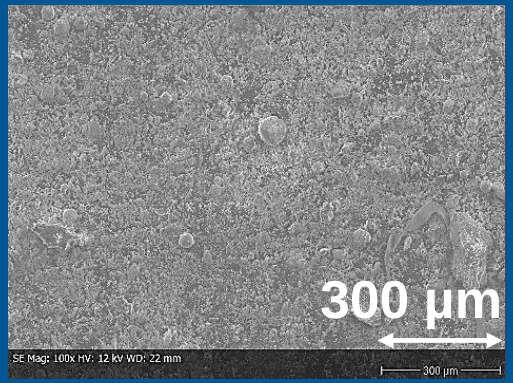
%	Ca	K	Mg	Si	Al	Fe	S	P	Mn	Cl
Fly Ash A	21.5	8.6	2.5	7.0	0.9	1.7	2.9	1.7	1.8	0.5
Fly Ash B	37.8	1.0	-	4.8	2.4	2.0	1.3	0.6	0.2	0.3

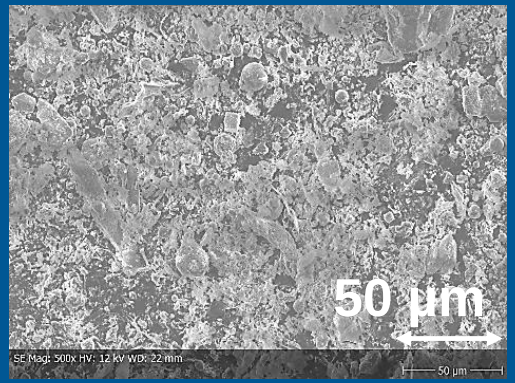
- Averages from measurements with two analysers: Olympus Vanta VMR and Niton XL3t 900S GOLDD

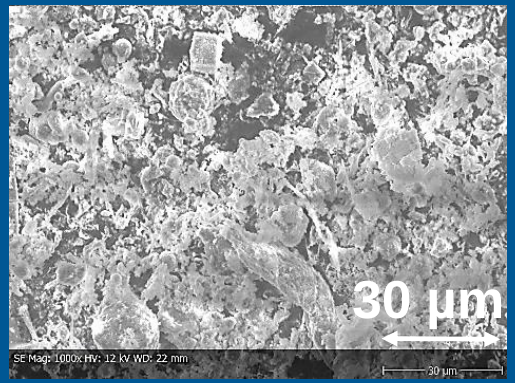
Figure 1. Ash samples packed in cups for the measurements.

Microstructure images

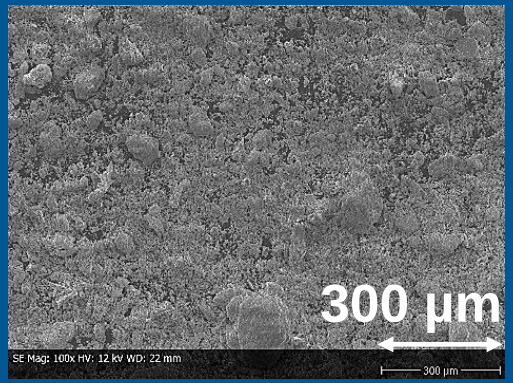
Ash A

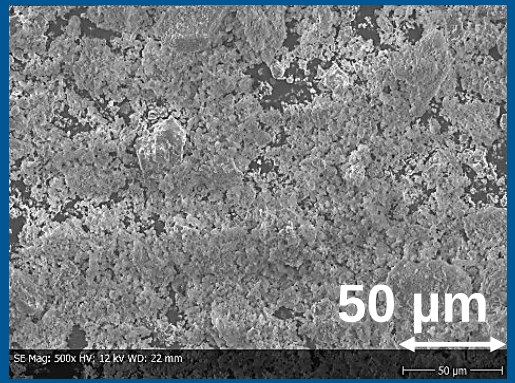


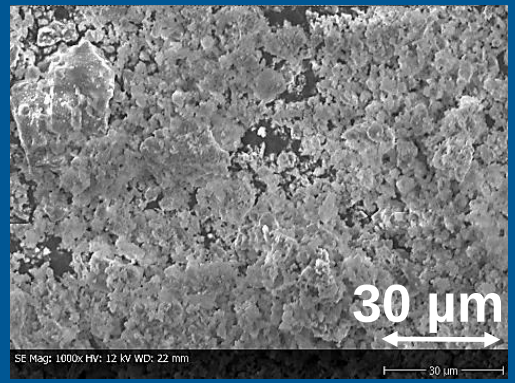




Ash B







Aggregation methods

Picture: Sampo Mäkikouri, VTT

	Aggregate manufacturing processes	Details	
1	**conventional water granulation**, Eirich mixer, *control sample*	72% Fly ash A, 28% H_2O	65% Fly ash B, 35%g H_2O
2	**carbonated water granulation,** Eirich mixer)	72% Fly ash A, 28% H_2O	65% Fly ash B, 35%g H_2O
3	**post-granulation CO_2 curing** after Eirich mixer	90bar, 80°C, 18h, H_2O	90bar, 80°C, 18h, H_2O
4	**tumbling drum granulation with water**	58% Fly ash A, 42% H_2O	50% Fly ash B, 50%H_2O
5	**simultaneous tumbling drum granulation and CO_2 curing**	58% Fly ash A, 42% H_2O	50% Fly ash B, 50%H_2O

Granulation equipment: Eirich mixer

- Used in processes 1-3
- For process alternative 3, the aggregates were placed in a glass of water and exposed to CO_2 in an autoclave

Figure 1. Eirich mixer

Granulation equipment: tumbling drum

- Water and ash mixed in a separate vessel for to get even moisture.
- Tumbling drum sealed after adding moist ash → slightly vacuumed → bottle CO_2 in.
- Rotation for ~30 min.
- Increase yield by removing produced granules detaching non-granulated mass.

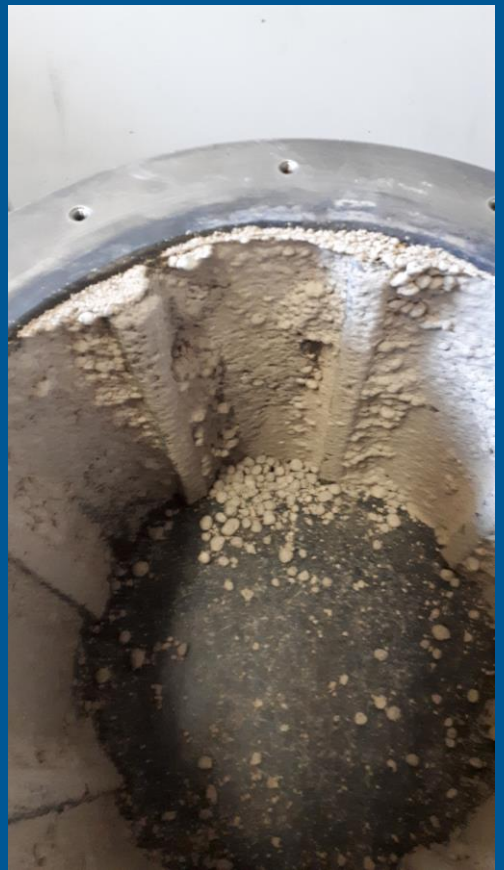


Figure 1. Inside the tumbling drum.

Analysis of the aggregates

Picture: Sampo Mäkikouri, VTT.

The products: sized 1-15 mm

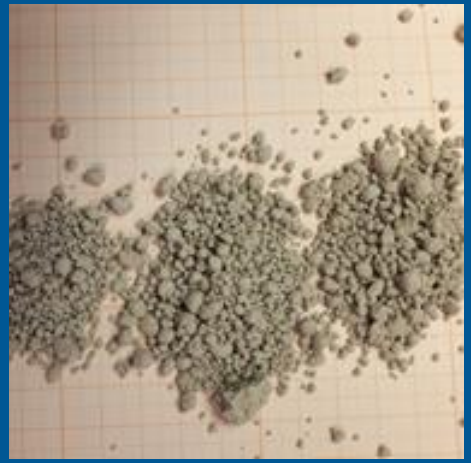


Figure 1. Fly Ash B, conventional water granulation.

Figure 2. Fly Ash A, conventional water granulation.

Figure 3. Fly Ash A, tumbling drum granulation with CO_2.

Bulk densities of the aggregates

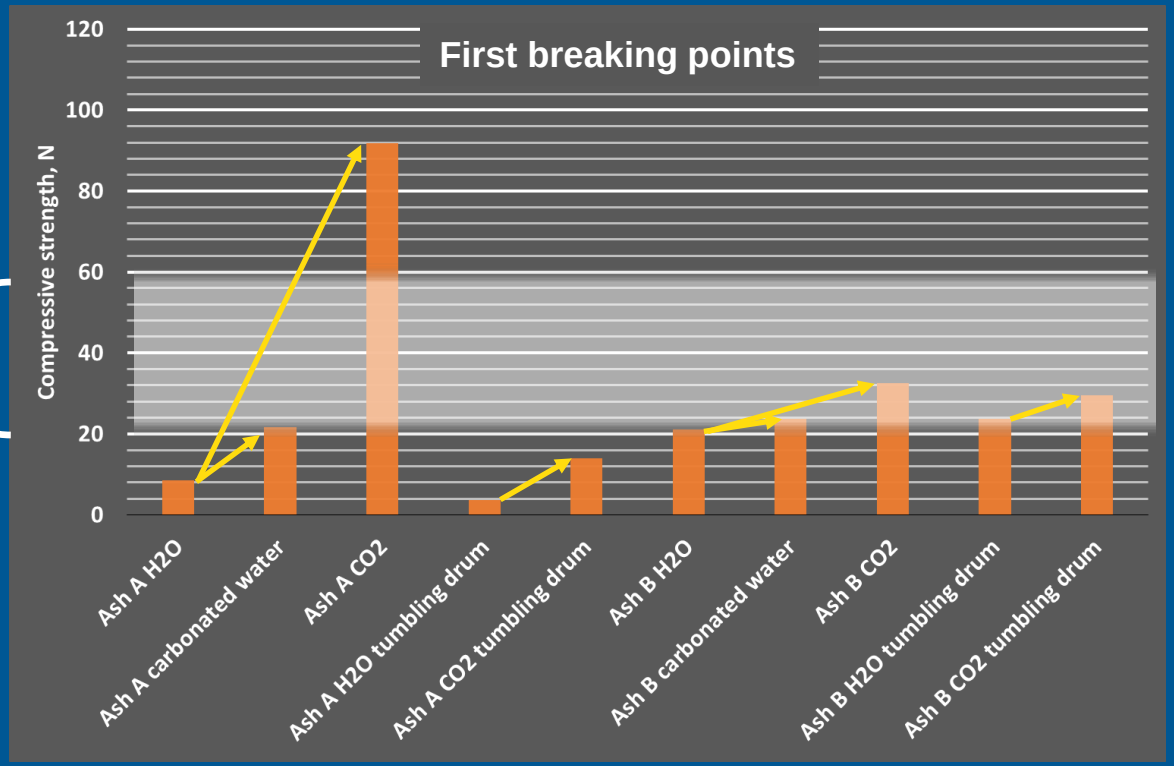
Product	Bulk density [kg/m^3]
Fly ash A CO_2 aggregate*	**730**
Fly ash B CO_2 aggregate*	**700**
Commercial expanded clay lightweight aggregate	235
Commercial crushed rock fines 0-5 mm	1600

***Aggregate process #5: simultaneous tumbling drum granulation and CO_2 curing. NOTE: small sample volumes!**

Average compressive strengths

All CO_2 processing methods **increased compressive strength!**

For comparison, commercial expanded clay aggregates were in the range of 20-60 N

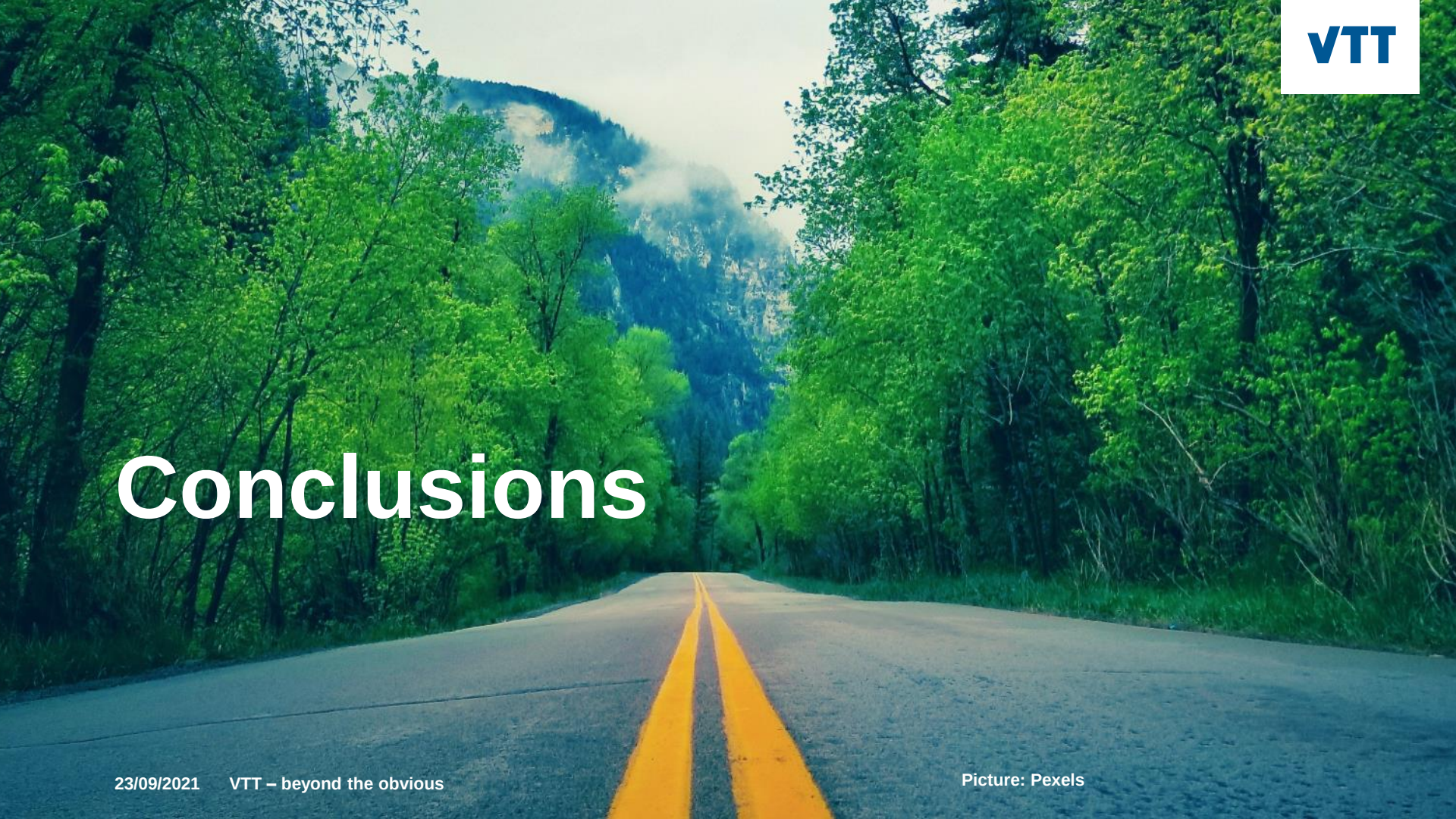


Increase in CO_2 uptake vs. control

Process	Fly ash A / PyroMK14	Fly ash A / TG-DSC-QMS	Fly ash B / PyroMK14	T
1. Conventional water granulation (control)	n/a	n/a	n/a	
2. Carbonated water granulation	0.96x	-	1.04x	
3. Post-granulation CO_2 curing	1.9x	2.1x	2.5x	
4. Tumbling drum granulation with water	1.7x		0.89x	-
5. Simultaneous tumbling drum granulation and CO_2 curing			1.7x	1.7x

1 ton of carbonated ash could bind *up to 166 kg more CO_2 vs. control* as granules

Very similar results with PyroMK14 and TG-DSC-QMS



Conclusions

Picture: Pexels

Conclusions

- Artificial aggregates made of two biomass fly ashes, water, carbonated water and bottle CO_2 with five processess
- All carbonation methods increased the crush strength of granules
- Up to 166 kg/t higher CO_2 uptake vs. control – control is not zero!
- Bulk density ~700-730 kg/m3 → business & climate benefit opportunity in replacing other lightweight aggregates

Figure 1. Our very first aggregates out of the CO_2 autoclave.

Help us

- By giving your professional feedback
- Suggesting equipment manufacturers for pilot-scale production
- Find industrial partners for piloting together

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In addition to their natural beauty, eskers provide ecosystem services, such as filter water, but they are also an important source of natural aggregates.
VTT
beyond
the obvious
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www.vtt.fi
Picture: Pyynikki esker in Finland, Sampo Mäkikouri, VTT.